

## BOOK REVIEWS

### **Beam Cooling and Related Topics (CERN 94–03)**

(Proceedings of Workshop held at Montreux, Switzerland, 4–8 October, 1993)

*edited by J Bosser*

CERN, European Organisation for Nuclear Research : Geneva, 1994

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The volume under review is the Proceedings of the periodic workshop organised by CERN for updating the state-of-art of the subject with the proliferation of high energy accelerators. Storage rings, rising costs for maintenance and the beam cooling techniques are gaining importance for effective utilisation of accelerator beams. The purpose of the workshop was to discuss the status of the different cooling techniques currently in use, namely stochastic, electron, ionization, heavy ion and laser and their actual performance, technological implications and future prospects. Theoretical principles of cyclotron maser cooling and muon cooling were also discussed. Interesting possibility of beam crystallisation in accelerators using ultimate cooling was also considered. As usual, in the beginning, a number of overview talks on the various techniques of cooling, their implications, present performance, and future prospects were presented before more detailed reports on all the topics were given in the form of oral presentation or poster sessions. Summaries by Chairman and Convenors of the various sessions are presented towards the end.

The workshop was attended by 80 participants from Western Europe, Russia, the USA and Japan. It may be recalled that the earlier workshops in this series were held at Karlsruhe 1984, Wertheim 1988, Legnaro 1990 and Tokyo 1992. These were mostly devoted to electron cooling.

In the overview session, seven talks were presented on the various techniques of cooling. It started appropriately with a talk by A. M. Sessler on Liouville's theorem and phase space cooling. This was followed successively by overviews on following topics : Theory, Technology and Techniques of Stochastic cooling; Electron cooling; status and perspectives; Laser cooling of stored ion beams; Muon cooling and applications; Medium and high energy electron cooling; and Physics of cooled beams. This was followed by six sessions for detailed consideration of individual techniques.

Cyclotron Maser cooling was deliberated upon with five presentations. Stochastic cooling was covered with three papers and Muon cooling had two. There was a long

session on Techniques and Technology which discussed eight papers before taking up Electron cooling. This old topic was discussed in six papers. Laser cooling session had four papers. These sessions were interjected with a poster session covering all the topics.

This time there were four papers on beam crystallisation. The pioneering work on the subject was done by E N Dementev *et al* in 1980 and the seminal work of J P Schiffer during 1984-85 paved the way for further work on the subject. The logical ultimate limit of beam cooling leads to an ordered crystalline array of particles. It should occur when the thermal energy (not counting collective oscillations) becomes much less than the Coulomb energy stored between two neighbouring particles in the beam. After the efficient electron coolers, the possibility of generating crystalline ion beams has gained the interest of particle accelerator physicists. In addition, new cooling methods like laser cooling gives further opportunity to reach ultra-cold system of particles in which ion can have state transitions to the crystalline phase.

The early electron cooling experiments at Novosibirsk (Dementev *et al*) and more recently in the TSR storage ring at Heidelberg (E Jachske *et al* 1990) and the SER storage ring at GSI (B Franke, 1991) have shown the extremely small momentum spread (below  $10^6$ ) are possible for small intensities (typically  $10^5$ – $10^6$  ions). The temperatures of such beams is of the order of a 1 K in beam direction, but several orders of magnitude higher transversely. Even lower temperatures (tens of mK) can be achieved in laser cooling, which works in the longitudinal direction.

Apart from the interest of accelerator physicists in these crystallised beams on the level of basic science, these systems represent a unique form of condensed matter, that is some 15 orders of magnitude less dense than 'normal' form of matter in the solid state, some of the features of such matter can also be studied in ion traps.

Dr. J P Schiffer of Argonne National Laboratory presided over the session of beam crystallisation and presented a summary at the end. His remarks on the future prospects of the subject were as follows : "My guess is that within next two years, the evidence for ordering in one and two dimensional beams will become firmer at the storage rings with laser cooling. Beyond  $N = 10^7$ , I would guess that there would have to be some conceptual and technical developments that would allow beams to attain constant angular velocity rather than constant linear velocity, before the forms of order may be realized in storage rings. But in the mean time many diagnostic questions have to be assessed. For instance, some thoughts and ideas are needed on how to separate the transverse beam temperature from coherent oscillations that are inherent to the beam and that do not disrupt order. And the consequences of the issue ..... that the momentum spread in the crystalline beam must be quite appreciable—though coherent, need to be considered".

The summary article (of the Proceedings) mentioned above, has one defect (editorial) that the references made in the text as well as the figures referred, do not tally with the reference list provided, nor the figures. There is reference for six figures though the text contains only one. In fact, the references and figures tally with Schiffer's (with

Hange) article 'Molecular Dynamics Simulations of Crystallisation of Ion Beams in Alternating Focussing Fields, and for Curved Trajectories' pp 279 (of the Proceedings).

The last topic that was considered in this workshop was 'Heavy Ions, High Energy Cooling'. There were eight presentations in this session which can be divided into three categories : new projects with electron cooling, new applications of the electron cooling and experimental and theoretical investigations of the electron cooling physics. Especially the last two papers of the session were devoted to detailed examination of the physics of electron cooling for heavy ions (upto  $\text{Au}^{79+}$ ).

At GSI in Darmstadt (Germany), the temperature of heavy ion beams in equilibrium between electron cooling and heating by intra-beam scattering has been measured over a large range of ion and electron beam intensities. A comparison of cooling force at small relative velocity for ions  $\text{C}^{6+}$ ,  $\text{Ti}^{22+}$  and  $\text{Au}^{79+}$  shows a strong increase with ion charge which however, favours a proportionality to  $Z^{1.5}$  to  $Z^2$ . In all experiments by now, a  $N^{1/3}$ -dependence of momentum spread *versus* the number (N) of stored particles has been observed. For the transverse emittance, results varied in the range  $N^{1/3}$  to  $N^{2/3}$ . Note that the observed lower limit for the detectable beam momentum spread  $7 \times 10^{-7}$  is likely to be caused either by the power supply ripple of the main ring magnets or by the energy instability of electron gun

The cooling force of the electron beam and the intra-beam scattering of the dense ion beams were investigated in separate experiments. Because of lack of adequate diagnostics of the transverse degree of freedom, the experiments were concentrated on longitudinal cooling force, cooling rate and longitudinal heating rate.

For three ion charges 6+, 22+ and 79+, increasing of the longitudinal cooling force can be described by a proportionality  $\propto Z^{1.5}$ . It should be noted that this law can be determined without knowing the absolute value of the diffusion coefficient  $D$ , and that the same charge dependence of the electron cooling force was measured at the TSR ring in Heidelberg for  $\text{D}^+$ ,  $\text{Li}^{3+}$ ,  $\text{C}^{6+}$ ,  $\text{O}^{8+}$  and  $\text{S}^{16+}$  ions.

It was clear that the technology of electron cooling of high energy has been developed. It will definitely open new feasibility in very high energy project. And, as a result of new experimental investigations (GSI and IUCF), the electron cooling physics for heavy ions has been understood in more details.

Overall, the Proceedings is a great stimulus and a update on beam cooling and will be referred by physicists in the field.

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**Proceedings of CERN, Geneva :**

1) 1994 European School of High Energy Physics & Addendum  
(Sorrento, Italy, 29 August – 11 September, 1994)

*edited by N Ellis and M B Gavela*

CERN-95-04 (Geneva, 1995)

xiii + 347 pages, illustrated; ISBN 92-9083-074-3

Addendum : 97 pages, illustrated; ISBN 92-9083-075-1

2) CERN Accelerator School (Vols. I and II)

(Fifth Advanced Accelerator Physics Course, Rhodes, Greece,  
20 September – 1 October, 1993)

*edited by S Turner*

CERN-95-06 (Geneva, 1995)

Vol I : xvii + 555 pages, illustrated; ISBN 92-9083-078-6

Vol II : xiii + 543 pages, illustrated; ISBN 92-9083-079-4

CERN, European Organization for Nuclear Research, Geneva, is holding regular international meetings or schools on topics of recent interests and activities centred around nuclear and accelerator research, and finally bringing out series of volumes most useful to nuclear scientists working all over the world. These volumes contain large number of articles which are well-written in a simplified and tutorial manner. The following is a brief introduction to the three volumes received by us in our editorial desk.

The first volume on High-Energy Physics is meant for young experimental physicists dealing with an introduction to the theoretical aspects of recent advances in elementary particle physics. The Proceedings contain lecture matters on field theory, standard model of electroweak interactions (except CP violation), beyond the standard model, quantum chromodynamics, CP violation reports on search for gravitational waves, stellar death and accounts of particle physics in which an introduction to collider physics is given. Recent experimental results from  $e^+e^-$  annihilation, ep and  $p\bar{p}$  collisions probing quantum chromodynamics have been discussed.

The second and third volumes, published in 1995, are follow-ups of earlier proceedings on advanced courses on accelerator physics. The present volumes are, in fact, intended to replace and to bring up to date all the materials which came up in earlier publications from 1985–91. The present volumes include sections on Hamiltonian equations and accelerator optics, chromaticity and dynamic beam aperture, particle tracking kinetic theory, longitudinal beam optics, coherent instabilities, beam-beam dynamics, intra-beam scattering, beam cooling, Schottky noise, beam radiation, neutralisation, beam polarisation, radio-frequency quadrupoles, space charge, superconducting magnets, crystal bending, beam-beam measurement and accelerator medical applications. These two

volumes with nearly 1000 pages, thus deal with almost all the important aspects of accelerator physics and its advancement in recent years. The volumes will thus be very much useful to accelerator physicists all over the world. We welcome these important publications from CERN.

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